学校编码：10384

学号：20720061152094

厦门大学

硕 士 学 位 论 文

利用微波能量原理的微波介质陶瓷应用研究

Development and Application of Microwave Dielectric Ceramics Based on the Principle of Microwave Energy

郑建森

指导教师：熊兆贤

专业名称：材料学

答辩日期：2009年7月

厦门大学学位论文原创性声明

本人呈交的学位论文是本人在导师指导下,独立完成的研究成果。本人在论文写作中参考其他个人或集体已经发表的研究成果，均在文中以适当方式明确标明，并符合法律规范和《厦门大学研究生学术活动规范(试行)》。

另外，该学位论文为(   )课题(组)的研究成果，获得(   )课题(组)经费或实验室的资助，在(   )实验室完成。(请在以上括号内填写课题或课题组负责人或实验室名称，未有此项声明内容的，可以不作特别声明。)

声明人(签名):

年　　月　　日

厦门大学学位论文著作权使用声明

本人同意厦门大学根据《中华人民共和国学位条例暂行实施办法》等规定保留和使用此学位论文，并向主管部门或其指定机构送交学位论文(包括纸质版和电子版)，允许学位论文进入厦门大学图书馆及其数据库被查阅、借阅。本人同意厦门大学将学位论文加入全国博士、硕士学位论文共建单位数据库进行检索，将学位论文的标题和摘要汇编出版，采用影印、缩印或者其它方式合理复制学位论文。

本学位论文属于：

(　　)1.经厦门大学保密委员会审查核定的保密学位论文，于　年　月　日解密，解密后适用上述授权。

(　　)2.不保密，适用上述授权。

(请在以上相应括号内打“√”或填上相应内容。保密学位论文应是已经厦门大学保密委员会审定过的学位论文，未经厦门大学保密委员会审定的学位论文均为公开学位论文。此声明栏不填写的，默认为公开学位论文，均适用上述授权。)

声明人(签名)：

年　　月　　日

摘　要

微波陶瓷介质谐振器具有体积小、重量轻、损耗低、温度稳定性好、价格便宜等优点，不仅有利于微波射频电路的集成化，是现代通信设备小型化、集成化的关键部件，而且近年来微波介质陶瓷在微波通讯领域的应用日趋广泛，但在微波加热方面的应用潜能尚未得到有效挖掘。本论文利用微波能量原理，先从材料的合成与制备角度出发，采用传统的固相法合成制备可低温烧结的 $Ba_5(Nb_{0.85}Sb_{0.15})_4O_{15}$ 陶瓷和中介电常数的 $Ca_{0.65}Ti_{0.65}La_{0.35}Al_{0.35}O_3$ 陶瓷，研究烧结助剂和工艺因素等对陶瓷结构与微波介电性能的影响，然后从器件设计和制造工艺方面，以本课题组承担完成的国家863计划项目“新型微波介质陶瓷材料与元件研制”为研究基础，探讨微波介质陶瓷在移动通讯和微波加热方面的应用。

首先采用微量添加 H_3BO_3、$MnCO_3$ 和 CeO_2 烧结助剂对 $Ba_5(Nb_{0.85}Sb_{0.15})_4O_{15}$ 陶瓷（简称BSN陶瓷）进行低温烧结，并对其烧结行为、显微结构和微波介电性能进行研究。实验表明：当添加1.0wt%的 H_3BO_3 和0.15wt%的 $MnCO_3$ 时，BSN陶瓷在940℃烧结取得较佳微波介电性能：ε_r=29.28，$Q\times f$ =17，113GHz，τ_f =+10.34ppm/℃；当添加1.0wt%的 H_3BO_3 和0.15wt%~0.75wt%的 CeO_2，烧结温度可控制在900~940℃，BSN陶瓷的微波介电性能可调控在 ε_r=28~31，$Q\times f$=16，000~23，000GHz，τ_f=+8~+18ppm/℃。还研究微量添加CuO和 $MnCO_3$ 烧结助剂对 $Ca_{0.65}Ti_{0.65}La_{0.35}Al_{0.35}O_3$ 陶瓷（简称CTLA陶瓷）的烧结行为、微观形貌和微波介电性能的影响。结果表明：当添加0.75wt%的CuO/$MnCO_3$，在1320℃烧结2h时，CTLA陶瓷获得优良的微波介电性能：$\varepsilon_r\approx$43，$Q\times f\approx$32，800GHz，$\tau_f\approx$+10ppm/℃，有效地降低了纯CTLA陶瓷的烧结温度且保持良好的微波性能，即 ε_r 值变化不大，$Q\times f$ 值保持良好，且 τ_f 值在±10ppm/℃之内。

其次以低介电常数 $MgTiO_3$-$CaTiO_3$ 微波介质陶瓷为材料，采用丙烯酰胺体系凝胶注模成型工艺成功制备出微波陶瓷基板应用于两款RFID陶瓷天线，并对比干压成型与凝胶注模成型工艺对样品微波介电性能的影响；以中介电常数CTLA和

$Ba(Mg_{0.2/3}Zn_{0.8/3}Nb_{2/3})$微波介质陶瓷为材料，利用微波能量原理，提出一种采用激光微调刻蚀提高制作微波陶瓷介质谐振器合格率的方法，并用该方法尝试制作出卫星天线用的微波陶瓷谐振器。

最后，以本课题组承担完成的国家863计划项目“新型微波介质陶瓷材料与元件研制”为研究基础，将相关成果积极转化到微波产品开发应用中，涉及到的微波介质陶瓷主要有$BaO-La_2O_3-TiO_2$、$Ba(Mg_{0.2/3}Zn_{0.8/3}Nb_{2/3})$和$MgTiO_3-CaTiO_3$，针对微波炉的热效率和加热均匀性问题，借助微波能量原理，解决均匀高效解冻等技术问题。

关键词：微波介质陶瓷；微波能量；射频天线；微波加热

Abstract

In this thesis, in the view of the synthesis materials, Ba5(Nb0.85Sb0.15)4O15 and Ca0.65Ti0.65La0.35Al0.35O3 ceramics were prepared via conventional mixing oxide route, and the effects of sintering aid and processing factors on chemical structure and dielectric properties of the samples were systematically investigated. In addition, in the view of the device design and manufacturing techniques, different kinds of microwave dielectric ceramics, including MgTiO3-CaTiO3, Ca0.65Ti0.65La0.35Al0.35O3, Ba(Mg0.2/3Zn0.8/3Nb2/3) and BaO-La2O3-TiO2 ceramics were explored for the applications of mobile communication and microwave heating based on the principle of microwave energy.

Chemicals of H3BO3, MnCO3 and CeO2 were used as sintering additives to lower the sintering temperature for Ba5(Nb0.85Sb0.15)4O15, i.e.,BSN, ceramics. The sintering behavior, microstructure and microwave properties were investigated by XRD, SEM and network analyzer. With 1wt% H3BO3 and 0.15wt% MnCO3 addition, the BSN ceramics sintered at 940°C get excellent microwave dielectric properties of an εr value of 29.28, a Q×f value of 17,113GHz, and a τf value of +10.34ppm/°C. Microwave dielectric properties are adjusted for the ceramic Ca0.65Ti0.65La0.35Al0.35O3 + 1wt% H3BO3 + 0.15wt%~0.75wt%CeO2 sintered between 900°C and 940°C for 2 h, with values of Q×f≈16,000~23,000GHz, εr≈28~31 and τf≈+8 ~ +18ppm/°C.

The influence of CuO and MnCO3 additives on the sinterability, microstructure and microwave dielectric properties of Ca0.65Ti0.65La0.35Al0.35O3, i.e., CTLA, ceramics was investigated. The results indicated that the density and dielectric properties of CTLA ceramics could be improved by both low-level doping of CuO (up to 1 wt%) and MnCO3 (up to 0.75wt%). The sintering temperature of CTLA ceramics with addition of CuO/MnCO3 could be effectively reduced from 1450°C to 1320°C due to the liquid phase effects. Excellent microwave dielectric properties were achieved for the ceramic $Ca_{0.65}Ti_{0.65}La_{0.35}Al_{0.35}O_3$ + 0.75wt% $CuO/MnCO_3$ sintered at 1320°C for 2 h, with values of $Q \times f \approx 32{,}800$GHz, $\varepsilon_r \approx 43$ and $\tau_f \approx +10$ppm/°C.

Meanwhile, gel-casting forming process was successfully used to fabricate microwave ceramic substrates. The dielectric properties of $MgTiO_3$-$CaTiO_3$ ceramics prepared by gel-casting were compared with those by dry press forming. In addition, two kinds of microwave antennas were also developed with the gel-casting forming process.

A new method was presented for calculating frequency and Q-factor of dielectric resonator. A novel laser trimming procedure was utilized to adjust the frequency of practical ceramics for dielectric resonators aiming better performance. Experimental results showed that the resonant frequency increased after laser etching applied on either upper or lower surface of resonator; meanwhile, the Q-factor of dielectric resonator was improved.

Finally, some results, such as BaO-La_2O_3-TiO_2,$Ba(Mg_{0.2/3}Zn_{0.8/3}Nb_{2/3})$ and $MgTiO_3$-$CaTiO_3$ ceramics were applied for microwave products supported by the National High-Tech Research and Development Plan of China (Plan 863) under Grant No. 2001AA325100.

Keywords: Microwave dielectric ceramics; Microwave energy; RFID antenna; Microwave heating

参考资料

[1]张瑜, 郝文辉, 高金辉. 微波技术及应用[M]. 西安：西安电子科技大学出版社,2006
[2]王子宇. 微波技术基础[M]. 广州：北京大学出版社,2003
[3]牛忠霞, 雷雪, 张德伟. 微波技术及应用[M]. 北京：国防工业出版社,2005
[4]Wersing W. Microwave Ceramics for Resonators and Filters[J].Curr. Opin. Solid State Mater. Sci., 1996,1 (5):715-731
[5]Cava R J. Dielectric Materials for Applications in Microwave Communications[J].J. Mater.Chem.,2001,11 (1):54-62
[6]Reaney I M, Iddles D. Microwave Dielectric Ceramics for Resonators and Filters in Mobile Phone Networks[J]. J. Am. Ceram. Soc., 2006,89 (7):2063-2072
[7]曲秀荣, 贾德昌. 微波介质陶瓷的研究进展[J]. 硅酸盐通报, 2006, 25(6):144-147
[8]李标荣, 王筱珍, 张绪礼. 无机电介质[M]. 武昌：华中理工大学出版社,1995
[9]何进, 杨传仁. 微波介质陶瓷材料综述[J]. 电子元件与材料,1995,14(2):7-13
[10]宋英, 王福平. 微波介质陶瓷材料的研究进展[J]. 材料科学与工艺,1998,6(2):59-63
[11]肖定全, 杜若晰, 熊雅玲. 微波介质陶瓷的近期研究进展[J].功能材料,1995, 26(1):20-23
[12]郭秀芬. 陶瓷介质在微波技术中的应用[J]. 压电与声光, 1990,12(6):40-47
[13]Richtmyer R D. Dielectric Resonator[J]. J. Appl. Phys., 1939,10:391-398
[14]张绪礼. 电介质物理与微波介质陶瓷[J]. 压电与声光, 1997, 19(5):29-33
[15]张绪礼, 王筱珍, 汤清华. 微波介质陶瓷与器件[J]. 电子科技导报,1997, (6):315-320
[16]赵梅瑜, 王依琳. 低温烧结微波介质陶瓷[J]. 电子元件与材料,2002,21(2):30-33.
[17]王宁, 赵梅瑜, 殷之文. 微波介质陶瓷的中低温烧结[J]. 无机材料学报,2002,17(5):915-923
[18]Jean J H , Gupta T K. Design of Low Dielectric Glass+Ceramics for Multiplayer Ceramic Substrate[J]. IEEE Trans. Comp. Packaging Manuf. Technol. B, 1994, 17(2):228-233
[19]孟中岩, 姚熹. 电介质理论基础[M]. 北京：国防工业出版社,1980
[20]郭秀芳. 陶瓷介质在微波技术中的应用[J]. 压电与声光,1990,12(6):40-47
[21]张迎春. 铌钽酸盐微波介质陶瓷材料[M]. 北京：科学出版社,2005
[22]范协诚. MRAlO4（M=Sr,Ca;R=La,Nd,Sm,Y）微波介质陶瓷的基础问题及其改性[D]. 浙江大学, 2008
[23]Cohn S B. Microwave Bandpass Filters Containing High-Q Dielectric Resonator[J]. IEEE Trans. Microwave Theory Tech.,1968, MIT-16(4):218-227
[24]O’Bryan H M, Thomson J. Phase Equilibria in the TiO2-rich Region of the System BaO-TiO2[J]. J. Am. Ceram. Soc., 1974, 57(12):522-526
[25]Wakino K et al. Dielectric Materials for Dielectric Resonators, 1976 Joint Convention Record of Four Institute of Electrical Engineers[C]. Japan, No.235
[26]Desu S B, O’Bryan H M. Microwave Loss Quality of BaZn13Ta2/3O3 Ceramics[J]. J. Am. Ceram. Soc. ,1985, 68(10):546-551
[27]Banno H, Mizuno F, Takeuchi T, et al. Dielectric Properties of Sr(Ni1/3Nb2/3)O3-Ba(Ni1/3Nb2/3)O3 Ceramics at Microwave Frequencies[J]. Jpn. J. Appl. Phys.,1985, suppl.,24-3:87-89
[28]Nomura S. Ceramics for Microwave Dielectric Resonator[J]. Ferroelectrics,1983,49:61-70
[29]Kagata H,Inoue T,Kato J, et al. Low-fired Bismuth-based Dielectric Ceramics for Microwave Use[J]. Jpn. J. Appl. Phys., part1,1992, 31(9B):3152-3155
[30]钟明蓉. Ba2Ti9O20微波介电陶瓷之制备及其微波特性之研究[D].台湾中原大学,2001
[31]王俊傑. ZnNb2O6介电陶瓷材料烧结与微波特性之研究[D].台湾国立成功大学,2003
[32]李俊德. 复合钙钛矿型结构之铌氧化物陶瓷的结构与微波介电性质之关系[D].台湾国立成功大学 ,2007
[33]熊兆贤. 材料物理导论(第二版)[M]. 北京：科学出版社,2007:238-250

[34]Hu X, Chen X M and Wu Y J. Nd-substituted Ba(Mg1/3Ta2/3)O3 Microwave Dielectric Ceramics[J]. Mater. Lett.,2002,54:279-283
[35]Kawashima S. Influence of ZnO Evaporation on Microwave Dielectric Loss on Sinterability of Ba(Zn1/3Ta2/3)O3 ceramics[J]. Am. Ceram. Soc. Bull.,1993, 72(5):120-126
[36]Tamura H, Konoike T, Sakabe Y, et al. Improved High-Q Dielectric Resonator with Complex Perovskite Structure[J]. J. Am. Ceram. Soc.,1984, 67(4):C-59-C-61
[37]Davies P K, Tong J Z. Effect of Ordering-induced Domain Boundaries on Low-loss Ba(Zn1/3Ta2/3)O3-BaZrO3 Perovskite Microwave Dielectrics[J]. J. Am. Ceram.Soc.,1997, 80(7):1727-1740
[38]Matsumoto H, Tamura H and Wakino K. Ba(Mg,Ta)O3-BaSnO3 High-Q Dielectric Resonator[J]. Jpn. J. Appl. Phys., part1,1991, 30(9B):2347-2349
[39]Kawashima S, Nishida M, Ueda I, et al. Ba(Zn1/3Ta2/3)O3 Ceramics with Low Dielectric Loss at Microwave Frequencies[J]. J. Am. Ceram. Soc., 1983, 66(6):421-423
[40]Onoda M, Kuwata J, Kaneta K, et al. Ba(Zn1/3Nb2/3)O3-Sr(Zn1/3Nb2/3)O3 Solid Solution Ceramics with Temperature-Stable High Dielectric Constant and Low Microwave Loss[J]. Jpn. J. Appl. Phys., part1,1982, 21(12):1707-1710
[41]Ratheesh R, Sebastian M T, Tobar M E, et al. Whispering Gallery Mode Microwave Characterization of Ba(Mg1/3Ta2/3)O3 Dielectric Resonators[J]. J. Phys. D.,1999,32: 2821-2826
[42]Furuya M. Microwave Dielectric Properties and Characteristics of Polar Lattice Vibrations for Ba(Mg1/3Ta2/3)O3-A(Mg1/2Ta1/2)O3 (A=Ba,Sr,and Ca) Ceramics[J]. J.Appl. Phys.,1999, 85(2):1084-1088
[43]卞建江,赵梅瑜,姚尧等. Ba(Mg1/3Ta2/3(1+x))O3陶瓷烧结性、微观结构及微波介电性能[J]. 无机材料学报, 1998, 13(6):830-834
[44]Maeda M, Yamamura T and Ikeda T. Dielectric Characteristics of Several Complex Oxide Ceramics at Microwave Frequencies[J]. Jpn. J. Appl. Phys.,1987, suppl.,26(2):76-79
[45]Lee H J, Kim I T and Hong K S. Dielectric Properties of AB2O6 Compounds at Microwave Frequencies (A=Ca, Mg, Mn, Co, Ni, Zn, and B=Nb, Ta)[J]. Jpn. J. Appl. Phys.,part2, 1997,36(10A):1318-1320
[46]Lee H J, Hong K S and Kim S J. Dielectric Properties of MNb2O6 Compounds (where M=Ca, Mn, Co, Ni, or Zn) [J]. Mater. Res. Bull.,1997, 32(7):847-855
[47]Kan A,Ogawa H and Ohsato H. Influence of Microstructure on Microwave Dielectric Properties of ZnTa2O6 Ceramics with Low Dielectric Loss[J]. J. of Alloys and Comp.,2002, 337:303-308
[48]Katayama S, Yoshinaga I, Yamada N, et al. Low-Temperature Synthesis of Ba(Mg1/3Ta2/3)O3 Ceramics from Ba-Mg-Ta Alkoxide Precursor[J]. J. Am. Ceram. Soc., 1996,79 (8):2059-2064
[49]Renoult O, Boilot J P, Chaput F, et al. Sol-Gel Processing and Microwave Characteristics of Ba(Mg1/3Ta2/3)O3 Dielectrics[J]. J. Am. Ceram. Soc.,1999,75(12):3337-3340
[50]Kakegawa K, Wakabayashi T and Sasaki Y. Preparation of Ba(Mg1/3Ta2/3)O3 by Using Oxine[J]. J. Am. Ceram. Soc.,1986, 69(4):C-82-C-83
[51]Choy J H, Han Y S, Hwang S H, et al. Citrate Route to Sn-Doped BaTi4O9 with Microwave Dielectric Properties[J]. J. Am. Ceram. Soc., 1998, 81(12):3197-3204
[52]Negas T, Yeager G, Bell S, et al. BaTi4O9/Ba2Ti9O20-based Ceramics Resurrected for Modern Microwave Applications[J]. J. Am. Ceram. Soc. Bull.,1993,72(1):80-89
[53]Lin W Y, Speyer R F, Hackenberger W S, et al. Microwave Properties of Ba2Ti9O20 Doped with Zirconium and Tin Oxides[J]. J. Am. Ceram. Soc., 1999, 82(5):1207-1211
[54]Wu J M and Wang H W. Factors Affecting the Formation of Ba2Ti9O20[J]. J. Am. Ceram. Soc., 1988, 71 (10):869-875
[55]姚尧,赵梅瑜,吴文骏等. 固相法合成单相Ba2Ti9O20粉体[J]. 无机材料学报,1998,13 (6):809-812
[56]Kim W S, Hong T H, Kim E S, et al.Microwave Dielectric Properties and Far Infrared Reflectivity Spectra of the (Zr0.8Sn0.2)TiO4 Ceramics with Additives[J]. Jpn. J. Appl. Phys., part1,1998,37(9B):5367-5371
[57]Christoffersen R, Davies P K and Wei X H.Effect of Sn Substitution on Cation Ordering in (Zr1-xSnx)TiO4 Microwave Dielectric Ceramics[J]. J. Am. Ceram. Soc.,1994,77:1441-1450

[58]Takada T, Wang S F, Yoshikawa S, et al. Effect of Glass Additions on (Zr,Sn)TiO4 for Microwave Applications[J]. J. Am. Ceram. Soc.,1994,77(9):2485-2488
[59]Wakion K, Minai K and Tamura H. Microwave Characteristics of (Zr,Sn)TiO4 and BaO-PbO-Nd2O3-TiO2 Dielectric Resonators[J]. J. Am. Ceram. Soc.,1984, 67(4): 278-281
[60]Ubic R, Reaney I M and Lee W E. Perovskite NdTiO3 in Sr- and Ca-doped BaO-Nd2O3-TiO2 Microwave Dielectric Ceramics[J]. J.Mater. Res.,1999, 14(4):1576-1580
[61]Sebastian M T. New Low Loss Microwave Dielectric Ceramics in the BaO-TiO2-Nb2O5/Ta2O5 System[J]. J. Mater. Sci. Mater. In El.,1999, 10: 475-478
[62]Webhofer A, Feltz A. Microwave Dielectric Properties of Ceramics of the System Ba6-x(SmyNd1-y)8+2x/3Ti18O54[J]. J. Mater. Sci. Lett.,1999, 18:719-721
[63]Dernovsek O, Naeini A, Preu G, et al. LTCC Glass-ceramic Composites for Microwave Application[J]. J. Eur. Ceram. Soc., 2001, 21:1693-1697
[64]谢道华,李智华,张永祥等. 中温系陶瓷的结构和介电性质研究[J]. 硅酸盐学报,1993,21(2):129-135
[65]Hong S, Kim E, Song H W, et al. Polaron Conduction Loss in Microwave Dielectric Ceramics[J]. J. Mater. Res., 1999, 14(2):500-502
[66]Ratheesh R, Sreemoolanadhan H, Sebastian M T, et al. Preparation, Characterization and Dielectric Properties of Ceramics in the BaO-Nd2O3-TiO2 System[J]. Ferroelectrics.,1998, 211:1-8
[67]Chen X M, Li Y. A- and B Site Cosubstituted Ba6-3xSm8+2xTi18O54 Microwave Dielectric Ceramics[J]. J. Am. Ceram. Soc. ,2002, 85 (3): 579-584
[68]Kim W S, Yoon K H and Kim E S. Far-infrared Reflectivity Spectra of CaTiO3 – Li1/2Sm1/2TiO3 Microwave Dielectrics[J].Mater. Res. Bull., 1999, 34(14-15): 2309-2317
[69]吕文中,张道礼,黎步银等. 高εr微波介质陶瓷的结构、介电性质及其研究进展[J]. 功能材料, 2000 (6):572-576
[70]Ezaki K, Baba Y, Takahashi H, et al. Microwave Dielectric Properties of CaO-Li2O-Ln2O3-TiO2 Ceramics[J]. Jpn. J. Appl. Phys.,part1,1993,32(9B):4319-4322
[71]Kato J, Kagata H and Nishimoto K. Dielectric Properties of Lead Alkaline-Earth Zirconate at Microwave Frequencies [J]. Jpn. J. Appl. Phys.,part1,1991,30(9B):2343-2346
[72]Kucheiko S, Choi J W, Kim H J, et al. Microwave Characteristics of (Pb,Ca)(Fe,Nb,Sn)O3 Dielectric Materials[J]. J. Am. Ceram. Soc.,1997, 80 (11): 2937-2940
[73]Kato J, Kagata H and Nishimoto K. Dielectric Properties of (Pb,Ca)(Me,Nb)O3 at Microwave Frequencies[J]. Jpn. J. Appl. Phys., part1,1992,31(9B):3144-3147
[74]Nakano M, Suzuki K, Miura T J, et al. Low-Temperature-Fireable Dielectric Material Pb(Fe2/3W1/3)O3-(Pb, Ca)(Fe1/2Nb1/2)O3 for Microwave Use[J].Jpn. J. Appl. Phys., part1, 1993, 32(9B):4314-4318
[75]Kagata H, Kato J, Nishimoto K, et al. Dielectric Properties of Pb-Based Perovskite Substituted by Ti for B-site at Microwave Frequencies[J]. Jpn. J. Appl. Phys., part1, 1993, 32(9B):4332-4334
[76]Park H S, Yoon K H and Kim E S. Relationship between the Bond Valence and the Temperature Coefficient of the Resonant Frequency in the Complex Perovskite (Pb1-xCax)[Fe0.5(Nb1-yTay)0.5]O3 [J]. J. Am. Ceram. Soc.,2001, 84(1): 99-103
[77]Moon J H, Jang H M, Park H S, et al. Sintering Behavior and Microwave Dielectric Properties of (Ca,La)(Ti,Al)O3 ceramics[J]. Jpn. J. Appl. Phys., part1, 1998, 38(12A):6821-6826
[78]Jancar B, Suvorov D and Valant M. Microwave Dielectric Properties and Microstructural Characteristics of Aliovalently Doped Perovskite Ceramics Based on CaTiO3[J].Key Eng. Mater.,2002,206-213:1289-1292
[79]Huang C L, Chen Y C. Low Temperature Sintering and Microwave Dielectric Properties of SmAlO3 Ceramics[J]. Mater. Res. Bull., 2002, 37:563-574
[80]Sebastian M T. Dielectric Materials for Wireless Communication[M]. Oxford, Aug.2008
[81]Fiedziuszko S J, Holmes S. Dielectric Resonators Raise Your High-Q[J]. IEEE Microwave Mag.,2001, 3(2): 50-60
[82]Sebastian M T, Jantuen H. Low Loss Dielectric Materials for LTCC Applications: a Review[J]. Int. Mat.

Rev., 2008,53(2):57-90
[83]Imanaka Y. Multilayered Low Temperature Cofired Ceramics (LTCC) Technology[M]. Springer, Dec. 2004
[84]章锦泰,许赛卿,周东祥,熊兆贤,方永汉. 微波介质材料与器件的发展[J]. 电子元件与材料 ,2004,23(6):6-9
[85]Reaney I M, Iddles D. Microwave Dielectric Ceramics for Resonators and Filters in Mobile Phone Networks[J]. J. Am.Ceram.Soc.,2006,89 (7):2063-2072
[86]李标荣,莫以豪,王筱珍. 无机介电材料[M]. 上海：上海科学技术出版社,1986,58-59
[87]Hakki B W, Coleman P D. A Dielectric Resonator Method of Measuring Inductive Capacitance in Millimeter Range[J]. IEEE Trans. Microwave Theory Tech.,1960, MTT-8:402-410
[88]Kobayashi Y, Katoh M. Microwave Measurement of Dielectric Properties of Low-loss Materials by the Dielectric Rod Resonator Method[J]. IEEE Trans. Microwave Theory Tech., 1985, MTT-33(7):586-592
[89]Courtney W E. Analysis and Evaluation of a Method of Measuring the Complex Permittivity and Permeability of Microwave Insulators[J]. IEEE Trans. Microwave Theory Tech.,1970, MTT-18(8):476-485
[90]Choy J H, Han Y S, Huang S H, et al. Citrate Route to Sn-Doped BaTi4O9 with Microwave Dielectric Properties[J]. J. Am. Ceram. Soc., 1998, 81 (12):3197-3204
[91]Kim J R,Kim D W,Jung H S,et al. Low-temperature Sintering and Microwave Dielectric Properties of Ba5Nb4O15 with ZnB2O4 Glass[J]. J. Eur. Ceram. Soc.,2006,26:2105-2109
[92]Kim J D,Kim E S. Low Temperature Sintering and Microwave Dielectric Properties of Ba5Nb4O15 Ceramics[J]. J. Korea. Ceram. Soc.,2004,41(10):783-787
[93]Valant M,Suvorov D and Kolar D. Role of Bi2O3 in Optimizing the Dielectric Properties of Ba4.5Nd9Ti18O54 Based Microwave Ceramics[J]. J. Mater. Res.,1996,11(4):928-931
[94]Yamamoto H, Koga A, Shibagaki S, et al. Low Temperature Firing of MgTiO3-CaTiO3 Microwave Dielectric Ceramics Modified with B2O3 or V2O5[J]. J. Jpn. Ceram. Soc.,1998, 106(3):339-343
[95]Roulland F, Terras R, Allainmat G, et al. Lowering of BaB′1/3B″2/3O3 Complex Perovskite Sintering Temperature by Lithium Salt Additions[J]. J. Eur. Ceram. Soc.,2004,24:1019-1023
[96]张冲,肖芬,邱红等. Ba5(Nb1-xSbx)4O15陶瓷的低温烧结及其微波介电性能研究[J]. 电子元件与材料 ,2007,26(8):55-58
[97]Shannon R D, Prewitt C T. Effective Ionic Radii in Oxides and Fluorides[J].Acta. Cryst.,1969, B25:925-946
[98]Silverman B D. Microwave Absorption in Cubic Strontium Titanate[J]. Phys. Rev.,1962,125:1921-1930
[99]Gadalla A M M, Ford W F and White J. Equilibrium Relationships in CuO-Cu2O-TiO2[J].Trans. Br. Ceram. Soc.,1963,62(1):57
[100]Janney M A, Omatete O O. Method for Molding Ceramic Powders Using a Water-based Gelcasting[P]. United States Patent 5028362,1991.07.02
[101]Janney M A. Method for Molding Ceramic Powders[P]. United States Patent 4894194, 1990.01.16
[102]王红洁,贾书海,王永兰等. Si3N4陶瓷的凝胶注成型工艺[J]. 西安交通大学学报,2001,35(4):403-406
[103]曹小刚,田杰谟. 多孔氧化铝陶瓷的凝胶注模成型[J].功能材料,2001,32(5):523-524,528
[104]中国科技部等十五部委. 中国射频识别(RFID)技术政策白皮书[R]. 北京：中国科技部,2006
[105]傅献彩,沈文霞,姚天杨. 物理化学(第四版) [M]. 北京：高等教育出版社
[106]Aurivillius B. Mixed Bismuth Oxides with Layer Lattices Ⅱ Structure of Bi4Ti3O12[J]. Arkiv foer Kemi,1949,1:499-512
[107]Kikuchi T. Synthesis of a New Mix-layered Bismuth Titanate SrBi8Ti7O27[J]. J. the Less-common Metals,1977,52:163-165
[108]Takada T, Wang S F, Syoshikawa S, et al. Effect of Glass Additions on BaO-TiO2-WO3 Microwave Ceramics[J]. J. Am. Ceram. Soc.,1994,77(7):1909-1916
[109]倪尔瑚. 介质谐振器的微波测量[M]. 北京：科学出版社, 2005:1-8
[110]Ng H K, Leung K W. Frequency Tuning of the Dielectric Resonator Antenna Using a Loading Cap[J]. IEEE Trans. on Antennas Propag., 2005, 53(3):1229-1232

[111]Ng H K, Leung K W. Frequency Tuning of the Linearly and Circularly Polarized Dielectric Resonator Antennas Using Multiple Parasitic Strips[J]. IEEE Trans. on Antennas Propag., 2006, 54(1):225-230
[112]曹宇,李祥友,蔡志祥等. 激光微加工技术在集成电路制造中的应用[J].光学与光电技术 ,2006,4(4):25-28
[113]肖芬,骆超艺,陈赐海. 一种求解微波介质谐振器复介电常数的方法[J].固体电子学研究与进展 ,2007,27(2):226-229
[114]刘锋, 芮汉明. 微波技术应用于食品工业中存在的关键问题分析[J]. 食品与发酵工业 ,2006,32(7):83-86
[115]刘韩星, 欧阳世翕. 无机材料微波固相合成方法与原理[M]. 北京：科学出版社,2006
[116]GB/T 18800-2002.家用微波炉性能测试方法[S]. 北京：中国标准出版社,2002
[117]巨汉基. 微波炉腔体电磁场分布仿真及尺寸结构优化设计[D]. 电子科技大学,2008
[118]杨先玮. 微波炉电磁仿真与优化设计[D]. 电子科技大学, 2008
[119]朱建华, 梁飞, 汪小红等. 微波介质陶瓷材料介电性能间的制约关系[J]. 电子元件与材料, 2005, 24(3):32-35
[120]宋燎原. 微波加热系统设计及谐振腔内电磁场分布研究[D]. 中国石油大学,2007
[121]高建平. 矩形微波谐振腔单模谐振条件[J]. 沈阳航空工业学院学报, 2001(S3):4-6
[122]Pozar D M. 微波工程(第三版)(英文版)[M]. 北京：电子工业出版社,2006
[123]陈新桥. 高次模多注速调管电动力学系统的研究[D]. 中国科学院研究生院(电子学研究所), 2002
[124]杨阳, 黄卡玛. 一种新型TEM Cell特性阻抗的解析计算方法[J]. 四川大学学报(自然科学版), 2008, (01):81-83
[125]谢拥军, 王鹏, 李磊等. Ansoft HFSS基础及应用[M]. 西安：西安电子科技大学出版社, 2007